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# **TIMING AND FORMATION OF WRINKLE RIDGES IN THE TYRRHENA PATERA REGION OF MARS**

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Wrinkle ridges are distinctive linear to curvilinear arches topped by crenulated ridges and have been identified on the Moon, Mercury and Mars. Lunar wrinkle ridges, located mainly within the maria, may have volcanic [1] or tectonic [2] origins, or a combination of the two [3]. Ridges in the Yakima member of the Columbia River basalts are considered terrestrial analogs to wrinkle ridges; the Yakima ridges are thrust faults draped on the surface by layered basalt flows [4]. On the Earth and the Moon, wrinkle ridges are found within volcanic materials; because of this association, the presence of wrinkle ridges on other planetary surfaces has been used as a criterion for identifying volcanic plains [5].

Watters and Chadwick [6] observed an orthogonal network of wrinkle ridges in Hesperia Planum (20°S, 250°W), with ridges trending NW-SE and NE-SW. These ridges are attributed to "two superimposed episodes of buckling", suggesting two distinct compressional regimes. Recently, due to the presence of lava flow lobes and leveed channels, Greeley and Crown [7] identified an area within Hesperia Planum as a flank flow unit associated with Tyrrhena Patera. Hesperia Planum surrounds Tyrrhena Patera and embays the eroded shield of the volcano to the north and east.

The Tyrrhena Patera flank flow unit extends ~1000 km from the summit caldera to the southwest [7,8]. More than 55 wrinkle ridges have been identified on this flank flow unit. As in Hesperia Planum, there are two dominant ridge trends: NW-SE (roughly concentric to Hellas) and NE-SW (roughly radial to Hellas) [6,9]. Those trending NE-SW are aligned with a major ridge system SE of the flow unit and with the general trend of the flow unit.

The relationships between the lava flows and wrinkle ridges within the flank flow unit allow relative ages to be determined. Wrinkle ridges are classified as "post-flow" if flow lobes appear to arch over the rises undeformed, with no evidence of flow ponding on the upstream side of the ridge, or of flows breaching the rises (Figure 1). Ridges that appear to be contemporary with or older than the flow unit have also been identified. These "flow-associated" ridges appear to be topographic barriers to flows in some instances. Several flow lobes, when traced to their source, can be followed upstream until they intersect a ridge (Figure 2). These flows appear to emanate from wrinkle ridges - although the ~90 - 230 m/pixel resolution does not allow the precise relationship to be determined. The younger, post-flow ridges trend NW-SE, whereas the older, flow-associated ridges trend NE-SW (Figure 3). This pattern appears to be consistent across Hesperia Planum. Analysis of the highest resolution images available for Hesperia Planum (~90 m/pixel) reveals many instances of NW-SE trending ridges cross-cutting NE-SW trending ridges. Where a NW-SE trending ridge intersects a NE-SW trending ridge, a NW-SE trending scarp is seen on the surface of the NE-SW trending ridge, suggesting that the NW-SE ridge formed the superposed scarp by compression. Therefore, it appears that the NW-SE trending ridges are younger than the NE-SW trending ridges. The Tyrrhena Patera flank flow unit has 121 craters greater than 5 km in diameter (normalized to  $10^6 \text{ km}^2$ ), suggesting that the unit was emplaced during the Upper Hesperian [10]. According to Tanaka's [10] model 2, this corresponds to 3.55 - 3.7 b.y. ago, thus placing maximum and minimum ages on the NE-SW trending and NW-SE trending ridges, respectively.

Wrinkle ridges within Hesperia Planum and the Tyrrhena Patera flank flow unit that trend NW-SE appear younger than the flank flow unit; ridges trending NE-SW appear older than, or contemporaneous with, the flank flow unit. If both ridge sets formed by tectonic processes, the age relationships suggest that the local stress regime shifted by 90° after the emplacement of the Tyrrhena Patera flank flow unit. The orientation of the post-flow ridges (orthogonal to the flank flow unit and concentric to the Hellas Basin) and the presence of ridge-related scarps suggest a non-volcanic, compressional origin for these ridges. However, the presence of flow lobes apparently emanating from NE-SW oriented ridges suggest that these ridges may have a volcanic origin: they may represent feeder dikes or localizations of near-surface lateral lava transport. This is supported by alignment of the flank flow unit, individual flow lobes and lava channels

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with the flow-associated ridges. Thus, within the Tyrrhena Patera flank flow unit, it is likely that the older ridges have a volcanic component, whereas the younger ridges appear to be of tectonic origin.

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